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Electronics Letters, Vol. 34, No. 4, February 1998, pages 39 0 and 391 INSPEC Abstract Accession No. 5876495 & "Proc. of OECC '97 2 nd Optoelec. & Comms Conf.",1997,p.404-5 "Proceedings of the Optical Fiber Communication Conference", 1997, Optical Soc. of America, p. 324 Europhysics Letters, Vol. 15, No. 7, August 1991, pages 745- 751

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(54) Abstract Title

Reduction of stimulated Brillouin backscattering (SBS) in optical transmission systems

(57) The invention reduces stimulated Brillouin backscattering (SBS) in optical transmission systems by broadening the frequency spectrum of transmitted signals. In particular, the invention utilises the non-linear effects of self phase modulation (SPM) or cross-phase modulation (XPM) to counteract Brillouin scattering. Figure 1 shows an optical transmission link having a terminal TT, fibre LWF, amplifier AMP and receiving terminal TR. A plurality of laser-modulator devices LM1-LMn receive binary data signals DS1-DSn which modulate carrier signals of different wavelength. To further reduce the effects of Brillouin scattering, a plurality of amplitude modulated (AM) pump signals from sources PL1 -PLm may be fed into the fibre.

FIG 1

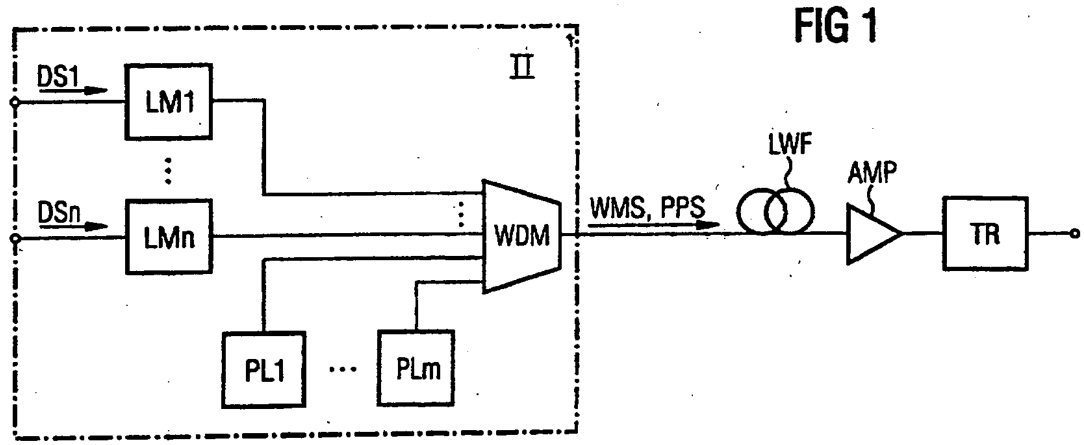

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FIG 1

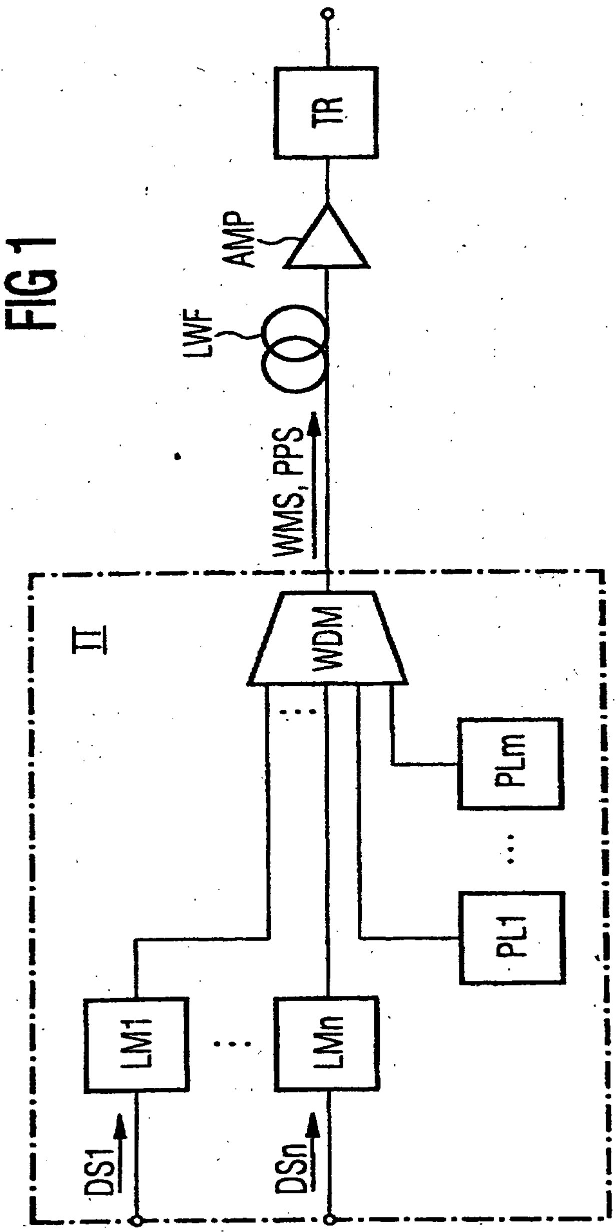
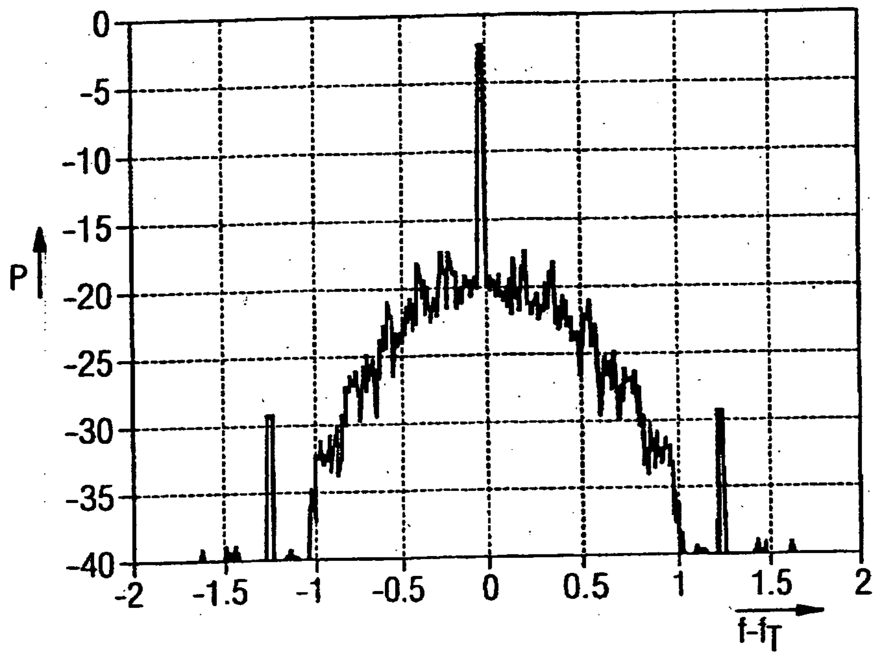


FIG 2


0
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-10
-15
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-25
-30
-35
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P
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-1
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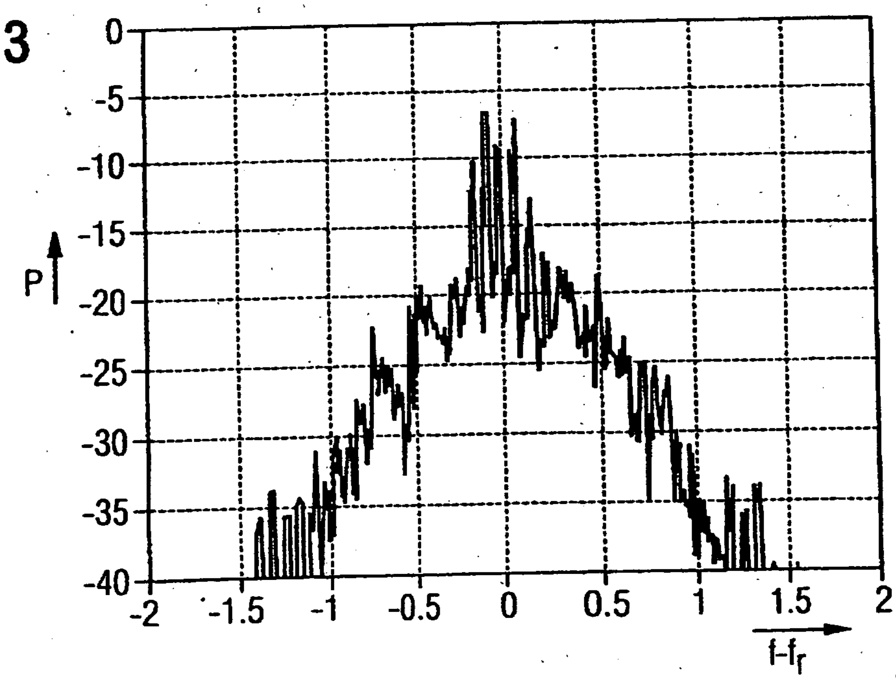
0
0.5
1
1.5
2
f-fT

FIG 3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-25
-30
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-1.5
-1
-0.5
0
0.5
1
1.5
2
f-fr

FIG 4

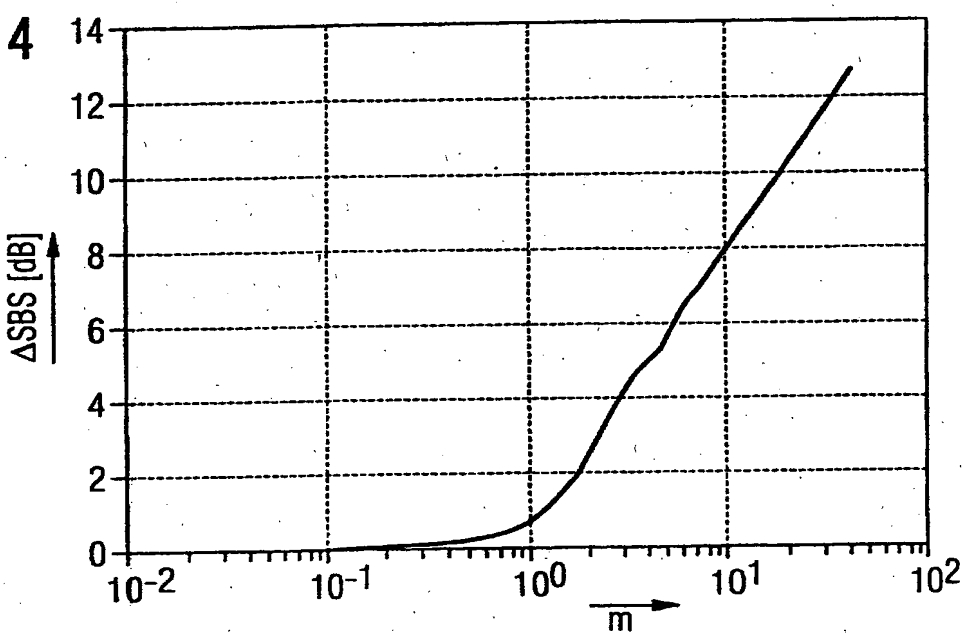
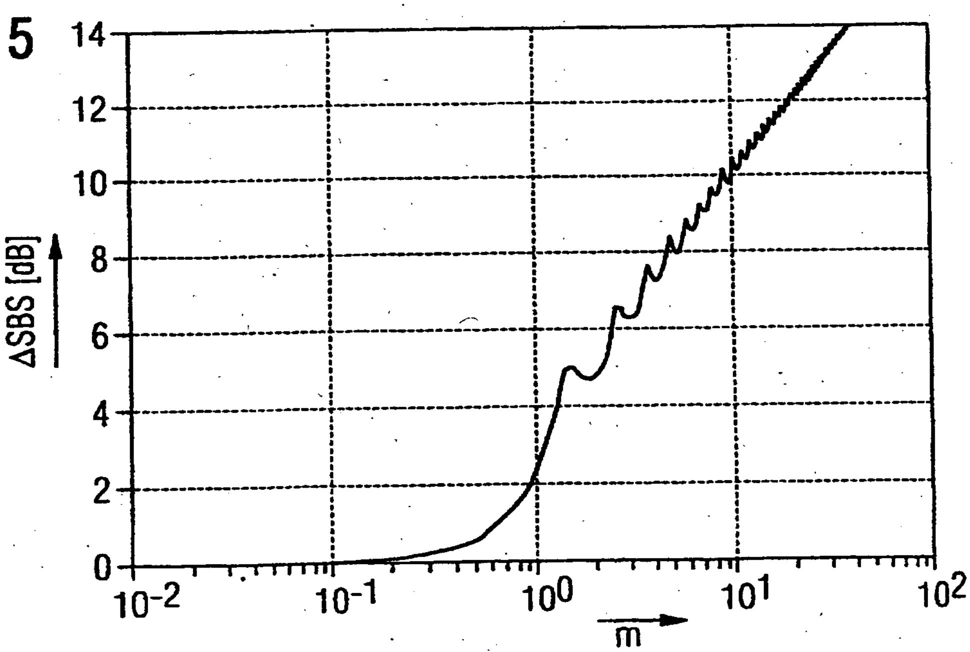

14
12
10
8
6
4
2
0
ΔSBS [dB]
10^{-2}
10^{-1}
10^{0}
10^{1}
10^{2}
m

FIG 5


14
12
10
8
6
4
2
0
ΔSBS [dB]
10^{-2}
10^{-1}
10^{0}
10^{1}
10^{2}
m

OPTICAL TRANSMISSION SYSTEMS

The present invention relates to optical transmission systems, and in particular to a method for reducing stimulated Brillouin backscattering, SBS, during the transmission of light pulses or light waves via an optical fibre.

If, in the case of the transmission of optical signals within a certain bandwidth, known as the Brillouin bandwidth, the power of the signal fed into a fibre exceeds a certain value, termed critical power or SBS threshold, optical backscattering is caused. This backscatters results in the transmitted power rising only underproportionally.

G.Smith described these effects in Applied Optics, November 1972, Vol. 11, No. 11, pages 2489 - 2494.

In Optical Fiber Telekommunications, Akademic Press, 1979, pages 133, 134, R.H. Stolen described the interrelationship between power and Brillouin backscattering for narrow and wide bandwidths.

In IEEE Journal of Quantum Electronics, Vol. QE-17, No. 6, June 1981 on page 927, Yamamoto presented an equation in which the bandwidth of the signal source was replaced by the bandwidth of the modulated signal. On the following page, he points out that the critical power for the Brillouin backscattering is dependent on the signal spectrum and rises with increasing data rate, which, as is well known, leads to a broader spectrum. Of course, in the estimation which is given, as also in the case of Stolen, it is necessary to take into account the requirement, indicated by Smith, that only the power inside the Brillouin bandwidth be taken into account for the different types of modulation, or determine a corresponding effective bandwidth.

Cotter, US Patent 4,560,246, uses angle modulation, which, in a known way, increases the

bandwidth, in order to reduce the Brillouin backscattering.

Apart from this, it is known from Physical Review A., Vol. 2, No. 1, July 1970, pages 60-67 that chirping of pulses increases the bandwidth, as a result of which, in accordance with Stolen and Yamamoto, the Brillouin backscattering is reduced. This chirping occurs as a frequently unwanted effect in the direct intensity modulation of a laser.

The result of all of these effects and measures is that the bandwidth of a light wave fed into an optical fibre, or of a light pulse which is fed in, is always increased, one consequence of which is other interfering effects.

The self phase modulation, which, at the start of a pulse, leads to the raising and then to the lowering of the frequency, also effects a broadening of the spectrum and, as soon as the Brillouin bandwidth is exceeded, a reduction in the Brillouin backscattering. By means of optical semiconductor amplifiers, wavelength converters and other non-linear components, a considerable self phase modulation can be generated, which leads to a considerable SBS reduction.

In ELECTRONICS LETTERS, 19th February 1998, pages 390 and 391, Horiuchi, Yamamoto and Akiba examined the effect of the cross-phase modulation on the spectra of WDM channels (WDM - wavelength division multiplex). In the case of this effect, the different transmission channels influence each other in such a way that a broadening of the spectrum likewise results. However, only at comparatively high powers does a relevant SBS suppression result.

It is desirable to provide a method for reducing the SBS, in which method an additional enlargement of the bandwidth of the optical signal which is fed in is not required.

According to one aspect of the present invention, there is provided a method for transmission of intensity-modulated light waves or light pulses via an optical fibre, wherein the light pulses have a spectral power density distribution which, without additional measures, causes Brillouin backscattering, characterised in that in the fibre, as a result of self phase modulation, a broadening of the frequency spectrum is generated, which reduces the stimulated Brillouin backscattering.

According to another aspect of the present invention, there is provided a method for parallel transmission of a plurality of intensity-modulated light waves or light-pulse sequences with different wavelengths via an optical fibre, the light waves or light pulses having a spectral power density distribution which, without additional measures, causes stimulated Brillouin backscattering, characterised in that the light waves or light-pulse sequences influence each other by means of cross-phase modulation in such a way that the frequency spectrum is increased at least in the case of one wavelength, and that the stimulated Brillouin backscattering is reduced.

First of all, the self phase modulation is used, which, at the start of a pulse, leads to the raising and then to the lowering of the frequency. This signifies a broadening of the spectrum, which, as soon as the Brillouin bandwidth is exceeded, leads to a reduction in the Brillouin backscattering. Decisive for this process is the Kerr effect, which is described in the relevant literature.

Another possibility is the utilisation of the cross-phase modulation between different light waves in wavelength division multiplex systems. In the case of this effect, the different transmission channels influence each other in such a way that a broadening of

the spectrum likewise results. As a result of optimisation of this mutual influencing, for example by selection of suitable frequency spacings between the transmission channels, this effect can be optimised.

Another solution can be achieved by feeding in at least one amplitude-modulated pump signal.

The use of an embodiment of the invention in optical WDM transmission systems is particularly advantageous. The SBS reduction already effected by the cross-phase modulation can be improved substantially by at least one amplitude-modulated pump signal.

In the case of a "standard monomode fibre", the feeding in of at least one amplitude-modulated pump signal having a frequency which lies above the Brillouin bandwidth, mainly between 20 MHz and 500 MHz, is particularly effective. In the case of low-dispersion fibres, higher frequencies can also be used.

In order to keep the pumping power of each pumping laser low, a plurality of amplitude-modulated pump signals are to be fed in, which are distributed as evenly as possible in terms of wavelength and, for example, lie at the edges and in the gaps of the transmission band. The frequency and the phase of all amplitude-modulated pump signals should be equal, in order that the effects accumulate. As a result of the low pumping powers and skilled selection of the wavelength, signal interferences as a result of stimulated Raman scattering are prevented to a great extent. The Raman scattering, which may be caused by amplitude-modulated pump signals, can be used, if appropriate, to improve the transmission properties, such as a correction of the tilt.

A broadband or directly modulated chirping laser or an incoherent light source can be used as the source for the amplitude-modulated pump signal.

A broadband pump signal can also include the useful channels if, as a result of this, the required signal-to-noise ratio is not fallen short of, for example in WDM systems with a channel data rate of up to 2.5 Gbit/s.

Reference will now be made, by way of example only, to the accompanying drawings, in which:

Figure 1 shows an arrangement for feeding in a plurality of amplitude-modulated pump signals;

Figure 2 shows the spectrum of an amplitude-modulated useful channel without cross-phase modulation;

Figure 3 shows the spectrum of an amplitude-modulated useful channel with cross-phase modulation;

Figure 4 shows SBS suppression by a pump signal fed into the transmission fibre; and

Figure 5 shows SBS suppression by a pump signal fed into a dispersion-compensating fibre.

Figure 1 shows an optical transmission link having a transmitting terminal TT, a transmission fibre LWF, an optical amplifier AMP and a receiving terminal TR. The transmitting terminal TT contains a plurality of laser-modulator devices LM1 - LMn, to which binary data signals DS1 - DSn are supplied. Each of these data signals modulates a carrier signal which has a different wavelength. The transmission signals WS1 to WSn generated in this way are combined by a wavelength division multiplexer WDM to form a wavelength multiplexed signal WMS, and are transmitted via an optical fibre LWF including a section amplifier AMP. Additionally, a plurality of amplitude-modulated pump signals PPS1 - PPSn (at least one pump signal) are fed into the transmission fibre LWF, which pump signals effect an additional cross-phase modulation and thus a reduction in the carrier amplitude. The feeding-in of the amplitude-modulated pump signals PPS1 - PPSn can

also take place in a dispersion-compensation fibre, DCF, connected upstream of the actual transmission fibre, and, of course, also via a further wavelength division multiplexer or another suitable coupling device.

The number of pump-signal sources PL1 - PLm and the power of the amplitude-modulated pump signals are chosen in accordance with the demands on the SBS suppression. Because of the low-pass effect of a dispersive fibre; sinusoidal modulation of the pump signal having a frequency above the Brillouin bandwidth of between 20 and 500 MHz should preferably take place. The amplitude-modulated pump signals are distributed in terms of wavelength in such a way and their power is adjusted in such a way that all of the transmission signals have a spacing with respect to the critical Brillouin power that is as equal as possible.

The spacings of the transmission signals with respect to each other can be chosen in such a way that as a result of mutual cross-phase modulation, they effectively support the SBS suppression. As a result of the distribution of the pumping energy among a plurality of sources, both SBS and signal interferences as a result of stimulated Raman scattering are avoided. Broadband lasers or incoherent light sources such as light-emitting diodes or super-fluorescence sources are used as pump-signal sources, in order to avoid SBS.

In all transmission signals (WS1 - WSn), the SBS is to be reduced as far as possible by the same value, that is the spacings with respect to the SBS threshold are to be at least substantially the same in all transmission channels.

In general, a substantially even improvement of the SBS suppression for all useful channels can already be achieved by turning (adjusting) the powers of the different pump sources. If appropriate, this can be

achieved by varying the channel spacings, different channel powers or further measures individual to the channel. Below the SBS threshold, importance can also be attached to same signal-to-noise ratios of the channels etc; the channel power can, for example, be adjusted individually within the scope predetermined by the SBS.

If the cross-phase modulation alone is able to suppress the SBS sufficiently, pump signals can be fed in, in the case of failure of individual signals or in the case of non-occupancy of individual transmission channels.

Figure 2 shows the frequency spectrum, the power P as a function of the frequency difference f - f_T (f_T - carrier frequency), of one of eight amplitude-modulated transmission channels with a data rate of 1.2 Gb/s in each case, without additional measures. The amplitude of the carrier reaches a value which leads to a considerable SBS.

Figure 3 shows the frequency spectrum of the same channel if an amplitude-modulated pump signal with a power of 160 mW and a modulation frequency of 7.8 MHz is additionally fed in.

In principle, it is also possible to use only one broadband amplitude-modulated pump-signal source, the spectrum of which includes the useful channels.

Figure 4 shows the raising of the SBS threshold (critical power) ΔSBS as a result of the feeding in of a pump signal into a standard monomode transmission fibre, as a function of the modulation index m. The latter is determined in the case of otherwise constant ratios of the power of the pump signal. The modulation frequency of the pump signal is adapted to the Brillouin bandwidth and is constant. As soon as the cross-phase modulation results in a broadening of the spectrum that goes beyond the Brillouin bandwidth, a

reduction of the SBS, or a raising of the critical power of the useful signal, results.

Figure 5 shows the alteration of the SBS threshold ΔSBS when the pump signal is fed into a dispersion-correcting fibre, DCF, as a function of the modulation index m. In this connection, a certain ripple as a function of the power of the pump signal is visible. An improved SBS suppression can sometimes be achieved in the case of a slightly reduced power.

As a result of the pump signals, a slight impairment of the eye opening can result because of the stimulated Raman scattering, as a result of which the reception quality is restricted somewhat. Because the pump signal or signals, however, are likewise present on the receiving side, the interferences can be eliminated by subtraction from the received signal or by an additional modulation of the transmission signals.

Claims

1. Method for transmission of intensity-modulated light waves or light pulses via an optical fibre, wherein the light pulses have a spectral power density distribution which, without additional measures, causes Brillouin backscattering, characterised in that in the fibre, as a result of self phase modulation, a broadening of the frequency spectrum is generated, which reduces the stimulated Brillouin backscattering.

2. Method according to claim 1, characterised in that the transmission takes place via fibres which have an increased self phase modulation in comparison with conventional fibres.

3. Method according to claim 1, characterised in that elements which effect as increased self phase modulation are inserted into the fibres.

4. Method for parallel transmission of a plurality of intensity-modulated light waves or light-pulse sequences with different wavelengths via an optical fibre, the light waves or light pulses having a spectral power density distribution which, without additional measures, causes stimulated Brillouin backscattering, characterised in that the light waves or light-pulse sequences influence each other by means of cross-phase modulation in such a way that the frequency spectrum is increased at least in the case of one wavelength, and that the stimulated Brillouin backscattering is reduced.

5. Method according to claim 4, characterised in that the spacings between the wavelengths are chosen in such a way that the frequency spectra of all light waves or light pulses are reduced.

6. Method according to one of the preceding claims, characterised in that the light-pulse sequences are generated by amplitude modulation.

7. Method according to one of the preceding claims, characterised in that additional measures for reducing the Brillouin backscattering take place as a result of broadening of the spectrum of the light wave which is fed in or of the light pulses which are fed in.

8. Method according to one of claims 4 to 7, characterised in that the light waves are additionally angle-modulated.

9. Method for suppressing stimulated Brillouin backscattering, SBS, during the transmission of an intensity-modulated optical transmission signal or of a plurality of intensity-modulated optical transmission signals (WS1 - WSn) having different respective wavelengths via an optical fibre (LWF), wherein the optical signals (WS1 - WSn) have a spectral power density distribution which, without additional measures, causes stimulated Brillouin backscattering, characterised in that at least one amplitude-modulated pump signal (PPS1 - PPSn) is fed into the optical fibre (LWF), which pump signal, as a result of cross-phase modulation, influences the optical transmission signals (WS1 - WSn) in such a way that their frequency spectrum is broadened in such a way that the stimulated Brillouin backscattering is reduced.

10. Method according to claim 9, characterised in that a plurality of amplitude-modulated pump signals (PPS1 - PPSn) are fed into the fibre, which pump signals are arranged in terms of wavelength in such a way that in all transmission signals (WS1 - WSn), spacings with respect to the critical powers causing SBS that are as equal as possible result.

11. Method according to claim 10, characterised in that the power of the individual amplitude-modulated pump signals (PPS1 - PPSn) is varied in such a way that in all transmission signals (WS1 - WSn), spacings with

respect to the critical powers causing SBS that are as equal as possible result.

12. Method according to one of claims 9 to 11, characterised in that the pump signals (PPS1 - PPSn) are amplitude-modulated with the same modulation frequency and the same modulation phase.

13. Method according to one of claims 9 to 12, characterised in that broadband amplitude-modulated pump signals (PPS1 - PPS2) are fed in, the spectra of which lie outside the transmission band of the transmission signals (WS1 - WSn) and/or between the transmission signals (WS1 - WSn).

14. Method according to one of claim 1 [sic], characterised in that at least one angle-modulated and amplitude-modulated pump signal (PPS1 - PPSn) is fed in, the spectrum of which includes the transmission signals (WS1 - WSn).

15. Method according to claim 13 or 14, characterised in that incoherent pump signals (PPS1 - PPSn) are fed in.

16 Method according to one of claims 9 to 15, characterised in that in wavelength division multiplex systems, in the case of failure or non-occupancy of at least one transmission signal (WS1 - WSn), at least one pump signal (PPS1 - PPSn) is fed in.

17. Method according to one of claims 9 to 15, characterised in that at least one pump signal (PPS1 - PPSn) having a modulation frequency which is greater than the Brillouin bandwidth and less than 600 MHz is fed into a standard monomode fibre.

18. Method according to one of claims 9 to 16, characterised in that the pump signals (PPS1 - PPSn) are sinusoidally modulated.

19. Method according to one of claims 9 to 17, characterised in that spacings in terms of wavelength between the transmission signals (WS1 - WSn) are chosen

in such a way that as a result of mutual cross-phase modulation, they support the suppression of the stimulated Brillouin backscattering by the amplitude-modulated pump signals (PPS1 - PPSn).

20. Method according to one of claims 9 to 18, characterised in that the modulation frequency and the power and also, if appropriate, the frequencies of the pump signals (PPS1 - PPSn) are tuned in such a way that spacings of the transmission signals (WS1 - WSn) with respect to the critical powers causing SBS that are as equal as possible result.

21. Method according to one of claims 4 to 19, characterised in that the interferences caused by cross-phase modulation by at least one pump signal (PPS1 - PPSn) are cancelled on the receiving side.

22. A method for transmitting intensity - modulated light waves or light pulses via an optical fibre, the light waves or light pulses being such as to cause Brillouin backscattering, wherein the method includes the step of promoting self-phase modulation, in order to broaden the frequency spectrum of the waves or pulses, thereby reducing such Brillouin backscattering.

23. A method for transmitting intensity - modulated light signals via an optical fibre, which light signals cause Brillouin backscattering in the fibre, wherein the method includes the step of broadening the frequency spectrum of the light signals, such that Brillouin backscattering is reduced.

24. A method as claimed in claim 23, wherein the broadening of the frequency spectrum is achieved by self-phase modulation of the light signals.

25. A method as claimed in claim 24, wherein the broadening of the frequency spectrum is achieved by cross-phase modulation of the light signals.

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Application No:	GB 0024944.1	**Examiner:**	Matthew Nelson
Claims searched:	1-22, 23 (partially), 24 & 25.	**Date of search:**	22 June 2001

Patents Act 1977
Search Report under Section 17

Databases searched:

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

UK Cl (Ed.S): H4B (BK18)

Int Cl (Ed.7): H04B 10/18

Other: Online: WPI, EPODOC, JAPIO, INSPEC

Documents considered to be relevant:

Category	Identity of document and relevant passage		Relevant to claims
X	GB 2319682 A	(FUJITSU) See e.g. the abstract.	23
X	GB 2309607 A	(FUJITSU) See e.g. the abstract.	23
X	EP 0767395 A2	(CSELT) See e.g. the abstract.	23
X	EP 0730190 A2	(AT & T) See e.g. the abstract.	23
X	EP 0595536 A1	(AT & T) See e.g. the abstract.	23
X	EP 0504834 A2	(NEC CORP.) See p. 3, line 31 - p. 4, line 5.	23
X	EP 0503579 A2	(GENERAL INSTRUMENT CORP.) See e.g. the abstract.	23
X	WO 94/00897 A1	(SYNCHRONOUS COMMS) See e.g. the abstract.	23
X	US 4560246	(COTTER) See whole document.	23
X	Electronics Letters, Vol. 34, No. 4, February 1998, Y. Horiuchi et al, "Stimulated Brillouin scattering suppression effects induced by cross-phase modulation in high power WDM repeaterless transmission", pages 390 and 391.		4-8, 23,25 at least

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
Y	Document indicating lack of inventive step if combined with one or more other documents of same category.	P	Document published on or after the declared priority date but before the filing date of this invention.
		E	Patent document published on or after, but with priority date earlier than, the filing date of this application.
&	Member of the same patent family		

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Application No: GB 0024944.1 **Examiner:** Matthew Nelson
Claims searched: 1-22, 23 (partially), 24 & 25. **Date of search:** 22 June 2001

Category	Identity of document and relevant passage	Relevant to claims
X	INSPEC Abstract Accession No. 5876495 & "Proceedings of OECC '97 2nd Optoelectronics and Communications Conference", published 1997, pp 404-405, Horiuchi et al "High power WDM repeaterless transmission incorporated with cross-phase modulation induced SBS suppression" (see online abstract).	1,2,22-24 at least
A	"Proceedings of the Optical Fiber Communication Conference", published 1997, Optical Society America, page 324, Ramachandran et al "Dispersion compensation techniques for CATV lightwave transmission systems".	
X	Europhysics Letters, Vol. 15, No. 7, August 1991 (Switzerland), T Afshar-Rad et al, "The effect of Self-Phase Modulation on Stimulated Brillouin Scattering in Filamentary Laser Plasmas", pages 745-751.	1,2,22-24 at least

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
Y	Document indicating lack of inventive step if combined with one or more other documents of same category.	P	Document published on or after the declared priority date but before the filing date of this invention.
&	Member of the same patent family	E	Patent document published on or after, but with priority date earlier than, the filing date of this application.